MATERIALS LABORATORY
FACTUAL REPORT 13-070

Bridge Collapse
Mount Vernon, WA; 05/23/2013

HWY13MH012

(40 Pages)

NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

January 13, 2014

MATERIALS LABORATORY FACTUAL REPORT Report No. 13-070

A. ACCIDENT INFORMATION

Place	:	Mount Vernon, Washington
Date	:	May 23, 2013
Vehicle	:	I-5 Bridge across the Skagit River
NTSB No.	:	HWY13MH012
Investigator	:	Robert Accetta, HS-20

B. COMPONENTS EXAMINED

I-5 Bridge, NBI No 4794A, Span 8

C. DETAILS OF THE EXAMINATION

Components of the bridge were examined on-scene between May 24 and June 5, 2013. No components were retained by the Safety Board.

Description of the Bridge

The I-5 bridge over the Skagit River was a 12 span bridge with 4 concrete approach spans at both the north and south ends and four 160 foot long steel through-truss spans over the river itself. Spans are numbered from the south to the north with the truss spans numbered 5 thru 8. Figure 1. The most northern truss span (span 8) had collapsed into the river.

The bridge was a symmetrical design about the east-west centerline between spans 6 and 7, and about the north-south centerline between the travel lanes. The truss spans were independent of each other and simply supported on each end. Each span was fixed at one end and rested on an expansion bearing at the other. For spans 7 and 8 the north ends were fixed. All steel bridge members had a light grey top coat of paint over a red orange primer.

The I-5 bridge was classified as “Fracture Critical”. All of the lower chord members along with several diagonals and verticals in each span were designated as fracture critical members. Fracture critical members for a typical span are shown in red in figure 1.

Each truss span had two riveted steel trusses, located on the east and west sides of the travel lanes. The truss design was of a Warren type with verticals. See Figure 2. A typical Warren truss does not have upper nodes at the ends of the span. However, for the I-5 bridge the ends of adjacent spans had been designed with no load vertical and horizontal members to form squared ends (see yellow highlighted members in figure 2). In a typical truss each member is loaded in either tension or compression and in this instance some members carry

no nominal loads. In figure 2 tension members are indicated in red, compression members are colored blue and no load members are black.

The east and west trusses were connected by riveted plate floor beams at the lower chord and by sway frames at and below the upper chords. The sway frames were truss structures made up of riveted structural shapes. The lower chords of the sway frames were esthetically curved to form archways across the traffic lanes. The lower chord of the sway frames are also referred to as the sway braces in this report. The upper and lower flanges of the sway brace are constructed from two pieces of L-angle steel, respectively that are riveted to the plate steel webs to form variable height I-beam shapes.

The north end of span 8 and the south end of span 5 are referred to as the north and south portals of the truss spans, respectively. The angled members of the east and west truss are connected by a heavily constructed portal frame of visually similar curvature to the lower chord of the sway frames. See Figure 3.

Diagonal lateral braces were present at the upper and lower chord for further stiffening. The deck was concrete supported on steel floor stringers between the floor beams with expansion joints between each span. As found on in the south bound lanes on span 7, the solid white line marking the west edge of the travel lanes (fog line) was located about 45 inches from the eastern vertical faces of the vertical members.

Upper and lower chord members of each truss were riveted box structures consisting of facing rolled “C” channels with perforated top and bottom cover plates riveted to the flanges of the “C” channels. The chords were nominally 15 inches square with varying wall thickness depending on location. Vertical and diagonals were either built up box or “I” sections, depending on loading conditions. All members were connected with various thickness gusset plates at the truss nodes.

The materials of the truss were specified as either ASTM[1] A7[2] carbon steel or ASTM A242[3] low alloy steel. ASTM A7 had a specified tensile strength of 60 to 72 ksi[4] and a specified minimum yield strength of 50% of the tensile strength but not less than 33 ksi. A242 specifies a steel with a minimum tensile strength of 70 ksi and a yield strength not less than 50 ksi. All of the fracture critical members were specified as A242 steel. In addition, A242 was specified for the end diagonals in each span. This included the north and south portals.

Terminology

Nodes are the connection points between truss members. They are composed of the ends of the associated members with gusset plates on either side. The nodes are numbered independently for each span from the south to the north starting at node 0 continuing to node

[1] ASTM International formerly known as The American Society for Testing and Materials.
[2] Specification for Steel for Bridges and Building. Withdrawn 1967 replaced by A36.
[3] Standard Specification for High-Strength Low-Alloy Structural Steel.

[4] Thousand pounds force per square inch

6. They are further identified as to whether they were associated with the east or west truss, E or W, and if they were from the upper or lower chords of the truss, U or L. Such that the third node from the south end in the upper chord of the west truss would be identified as node U3W. Individual truss members are identified based on the nodes that the components connect. So that a diagonal connecting nodes U3W to L2W would be identified as L2W-U3W. When necessary, the span number is also indicated. See figure 2.

As an example, sway frames and floor beams are referred to by the nodes that they connect. Such that the sway frame or brace connecting U4E to U4W would be the sway brace 4 or SB4.

Initial Examinations

The as-collapsed above water structure of span 8 was examined from boats, from the north and south piers and from a man-basket while suspended from a crane. Use of the man-basket allowed closer examinations of the structure between the trusses that was not accessible from a boat. While the man-basket facilitated arms-length visual examination of much of the structure, the configuration of the bracing and other bridge member did not allow the same level of examination for all components. See Figures 4 and 5

Initial inspections found that span 8 had completely collapsed into the Skagit River but was generally confined between its end piers. A prominent “V” shape was apparent across the collapsed span structure at U4E and U4W. South of the ”V”, the span structure was oriented nearly flat while the structure north of the “V” had rotated south end down such that the normally 45º north portal members were nearly horizontal. The upper chords of the east and west trusses were above the water and visually intact except around node U4W. At U4E and U4W both chords bent abruptly downward. The west upper chord entered the water and node U4W was not visible below the water line. The western upper chord became visible again about half way between node U4W and U5W on the rotated north side structure. The eastern upper chord bent downward at U3E then upward at U4E, but remained visible just above the water line, and then it bent again just south of U5E.

As collapsed, the chord lengths on either side of node U4W were displaced to the east approximately 8 feet.

The lower chords were mostly under water except for end portions that were leaning on the sides of the respective piers. On the north end, the lower chords of the east and west truss were visible and appeared intact between nodes 6 and to near nodes 5. The north end fixed pin assemblies were attached on both sides to the lower chords at nodes 6. The fasteners attaching the pin assemblies to the pier were present and the corresponding areas of the pier were fractured consistent with the rotation of the north portal. At the south end of span 8 a portion of the west truss lower chord was visible from node L0W (with bearing attached) to slightly past node L1W. The remaining length of the west lower chord and the entire eastern lower chord were underwater and not visible.

Initial underwater inspections found the lower chords of both trusses buried in the river bottom from about nodes 2 to the north sides on nodes 5 and not visible. The visible parts of

the lower chords were reported as intact and not fractured. The river was reported to be between 10 and 20 feet deep.

Most of the visible structure remained intact but deformed. On the visible portions of the western truss partial fractures were present in the upper west chord just north of the U3W node and just south of the U5W node. The U3W-L3W vertical was partially fractured adjacent to the U3W node and the sway frame lower attachment to the vertical was partially fractured but remained connected. As noted previously, the upper chord was not initially visible around the U4W node. On the eastern truss, the upper chord contained partial fractures in the deformed area at node U4E. Additionally, a partial fracture was visible in the U3E-L3W vertical member adjacent to the gusset plates and the rivets attaching the upper end of member L4E-U3E to U3E node were sheared and the member separated from the node.

Contact and impact damage and deformation was noted on the north portal and all of the sway braces above the southbound traffic lanes in span 8. The portal and sway brace damage is detailed in following sections.

The concrete roadway surface was visible in several places, some above water some slightly below the water line. Most sections of the deck were displaced from their original locations except at the far south end. As designed, the deck was not fastened to the underlying stringers.

Three vehicles were present in the collapsed span. See Figure 4.

Initial inspections of the remaining truss spans 5, 6 and 7, found undocumented damage to the U4W-L4W vertical and several sway braces over the southbound lanes on span 7 and previously documented[5] damage to the south portal and several sway braces over the north bound lanes of span 5.

Recovery

The collapsed span 8 was removed from the Skagit River by contractors for the Washington State Department of Transportation (WSDOT) under the direction of NTSB investigators. Initial removal began about May 27, 2013 with removal of the vehicles and was mostly complete by June 9, 2013. Removal methods included torch cutting both underwater and in air and by hydraulic shearing of members. Deck sections were reduced to rubble by hydraulic hammers and the reinforcement bars were removed by crane bucket. Underwater inspections were carried out throughout the process.

Eventually, the entire lower chord of both the east and west trusses were uncovered and visually examined underwater. On the west truss a complete separation was found at the north edge of the gusset for L4W. The eastern truss was also fractured adjacent to the south edge of the L4E gusset plates.

Select sections of the truss were lifted to the adjacent shore for closer inspections and documentation. They included nodes U5W, U4W, U3W, L4W, U4E and L4E and sections of

[5] Washington State Department of Transportation bridge damage report dated 10/22/2012.

the associated members. These pieces are documented in the following section. The remainder was examined for fracturing and pre-collapse damage as they were removed and loaded into a barge for release to WSDOT.

Detailed examinations

No instances of significant pre-existing corrosion or cracking were noted at any location during the examinations of the span 7 and 8 structures. Further, all fractures and cracks noted in any of the members were consistent with overstress forces. All measured components and subcomponents were consistent with drawing requirements.

West Truss

The west truss had four areas of major damage. Three of the damage areas were associated with the upper chord and nodes U3W, U4W and U5W. Member U3W-U5W connected all three nodes running from the middle of U3W continuously through node U4W and into node U5W. The forth damage area was at the L4W node.

U3W

Adjacent to the north edge of the U3W node, the upper chord was bent, north end down, and the chord was partially fractured. The top cover plate and both “C” channels of the chord were overstress fractured and the lower cover plate was buckled. Only the lower cover plate held the chord together. Deformation accompanying the fractures was consistent with down bending of the upper chord north of node U3W. See Figure 6.

At the node vertical U3W-L3W was bent about 45º with the lower end southward. The vertical was partially fractured at the lower edges of the U3W gusset plates. The north flanges were tension fractured and the south flanges were buckled consistent with the lower end of the vertical member being displaced to the south. The vertical was bent again at about mid-height with the lower end to the north.

U4W

Member U3W-U4W was severely deformed adjacent to U4W into a “V” formation with the node down and the north and south portions of the chord up. The permanent deformation was greater than 90º. See Figure 7. The deformation was localized and centered at the north edge of the U4W gusset plates. The deformation severely folded and “S”-bent the “C” channels and top cover plate of the chord in a manner consistent with compression buckling of the chord followed by bending. See Figure 8 Upper. In one area, the box section of the chord collapsed bringing the top and bottom cover plates into near proximity. Small local fractures were present and several rivets were separated at some areas of severe deformation. As-recovered, pieces of aluminum, wood and low voltage wiring consistent with camping trailer materials were found embedded in the space formed by the deformed chord and adjacent gussets of the U4W node. See Figure 8 Lower

The U4W-L4W vertical was partially fractured and several rivets were missing at the U4W connection but it remained attached to the node. The north side flanges of the vertical were fractured and the south flanges were buckled consistent with the lower end of the member displacing to the south. As recovered, the vertical was bent lower end to the south to about 45º just below the node. The U4W-L4W vertical was also partially separated at the top edge of the sway brace attachment area. The east flanges and web were completely fractured and only the west side flanges connected the sway brace to the vertical. The vertical was completely fractured at the lower edge of the sway brace attachment area.

L4W

As-recovered, node L4W was connected to the number 4 floor beam with node L4E at the other end.

Member L4W-L6W was completely fractured immediately adjacent to the north edge of the gusset plates for node L4W. The fracture was overstress with no indications of preexisting cracking or corrosion. The deformation adjacent to the fractures and in the top cover plate was consistent with bending overstress load as if the node were displaced downward relative to the adjacent nodes. See figure 9.

U5W

Member U3W-U5W was severely damaged and partially fractured about 2 feet south of the U5W node gusset plates. The lower cover plate and both “C” sides of the chord were completely fractured. The upper cover plate was fractured between the west edge and a hand hole and only the eastern ligament remained intact and holding the north and south side of the upper chord together. This ligament was later fractured during recovery. See Figure 10 Upper.

The “C” channel sides and lower cover plate of U3W-U5W were deformed adjacent to the fracture consistent with down and east movement of the U4W node. However, fracture features were more consistent with upward movement of the south end. The overall fracture and deformation pattern were consistent with an initial south end down motion deforming the chord followed by a south end upward motion fracturing the deformed structure. See Figure 10 Lower.

East Truss

Similar to the west truss, the majority of damage to the east truss was associated with the upper chord nodes U3E, U4E and U5E and lower chord node L4E and the interconnecting members.

U3E

Member U3E-U5E was bent north end down about 4 feet from the north edge of the node with partial fracturing of the top and bottom chord cover plates. The lower plate showed buckling deformation and the top plate was tension-fractured. See Figure 11.

U3E-L4E was disconnected from the node and rested on other structure to the west of the node. All of the gusset plate rivets were fractured with only a few remaining in either the member or the gusset plates. The upper ends of the “C” channel side plates of the member were deformed and the area between the gusset plates was damaged consistent with the member being forced upward.

The U3E-L3E vertical member was bent, lower end to the north, at the U3E gusset plates with buckling deformation on the north flanges and partial fracturing on the south flanges. The vertical also had a reversed bend at about its midpoint with the lower end to the south.

U4E

The U4E node was visible resting just above the water line. The upper chord, U3E-U5E, was bent more than 90º at node 4E with the majority of the deformation at the north edge of the node. The deformation was very similar to that seen at the U4W node and included severely folded and “S”-bent “C” channels and top cover plate consistent with compression buckling of the chord followed by bending. Small local fractures were present and several rivets were separated at some areas of severe deformation. See Figure 12.

L4E

Member L2E-L4E was completely fractured immediately adjacent to the south edge of the gusset plates for node L4E. The fracture was overstress with no indications of preexisting cracking or corrosion. The deformation adjacent to the fractures and in the top cover plate was consistent with bending overstress load as if the node were displaced downward relative to the adjacent lower nodes. Member L4E-L6E also displayed an upward deflection of the north end consistent with downward deflection of the node relative to the adjacent nodes. See figure 13.

U5E

Node U5E was intact. However, upper chord member U3E-U5E was bent south end down about 2 feet south of the node U5E gusset plates. The bend was approximately 45 degrees with the lower cover plate and “C” channel side plates heavily deformed and somewhat twisted. The L4E-U5E diagonal member was bent lower end to the north about 8 feet from the node. See Figure 14.

Sway Frames Span 8

Impact damage in the form of dents, deformation, tearing, scuffing and paint removal and paint transfer were found on all of the span 8 sway braces. All but one area of the damage was located over the right hand south bound traffic lane near the continuous white lane line (fog line). The contact marks were aligned in the direction of travel. Damage locations on the sway braces were measured from the inside (east) face of the associated vertical truss member.

North Portal

At the north portal, the south flange of the lower portal brace was partially torn and displace to the south. Damage was apparent from about 33 inches to about 80 inches from the vertical. Blue paint transfer was visible on the upper surface of the south (lower) flange of the brace. The transferred paint outlined a square corner shape with a 23 inch long horizontal mark and an eight inch long vertical at the west edge of the horizontal. The vertical line and corner were approximately 42 inches from the vertical member. The south flange was torn for about 36 inches and the south face plate was torn along a weld at 33 inches from the vertical. The flange and face plate were bent more than 12 inches to the south. See Figure 15.

Sway Frame 4

As collapsed, sway frame 4 was entirely underwater. When recovered, the sway brace showed significant deformation and contact damage over the right south bound traffic lane. The sway brace showed impact damage from about 33 inches to about 67 inches. The lower flange had a square tear between 34 inches and 41inch (7 inches). Measurements from the east face of the vertical member. One flange rivet was missing above the tear. The north flange was bent downward starting just inboard of the tear and extending east to about 71 inches. See Figure 16 Upper.

Beginning at the tear and extending to the east there was heavy gouging and contact marks along the north edge of the north flange. Blue paint transfers were apparent on top of the flange starting at 32 inches continuing intermittently to 67 inches. The blue paint transfers were consistent with the exterior paint of the oversize load discussed in a following section.

The entire lower chord of the sway frame was deformed and bowed to the south centered at the tear across the width of the traffic lane. The permanent deflection from straight measured about 24 inches at the tear. The lower chord of the sway brace remained attached to the vertical. However, the vertical was fractured as noted in a previous section. See Figure 16 Lower.

The lowest 6 fasteners connecting the sway brace to the vertical were nuts and bolts on both the north and south flanges. The remaining fasteners were rivets.

Sway Frame 3

Damage to the sway brace started about 76 inches from the vertical and continued for 48 inch to about 124 inches. The heaviest damage occurred at about 82 inches where both the upper and lower north flanges of the brace were bent downward and the upper flange was torn. Blue paint transfers and vertical gouging was present at both flanges. See Figure 17 Upper.

The sway brace attachment to the vertical was mostly fractured through the flanges of the connecting angles. Only short sections of the angles remained connecting the sway brace to the vertical. See Figure 17 Lower

The lower chord of the sway frame was deformed (bowed) to the south an estimated 12 inches centered at the impact area from its original straight condition. See Figure 18 Upper.

The impact damaged portion of sway brace was not recovered with node U3W.

Sway Frame 2

Damage to the sway brace was centered at about 84 inches from the face of the vertical with the north flange turned downward and both upper flanges wrinkled in this area. The lower north flange was torn near the west side of the damage and the flange was turn to the south at both sides of the tear. See Figure 18 Lower.

The lower chord of the frame was permanently bowed to south centered at the damage area. See Figure 18 Upper.

The sway brace attachment to the vertical remained intact. However, the vertical was deformed and twisted adjacent to the upper and lower ends of the sway brace. The vertical was prominently deformed both to the south and the east at the attachment.

Sway Frame 1

The lower north flange of the sway brace was damaged from about 80 inches to 90 inches from the vertical. The lower flange was bent upward but not torn. Deformation did not extend to the south flange. Blue paint transfers were apparent on the bottom side of the flange. See Figure 19.

The brace appeared straight and the attachment to the vertical was intact with no obvious damage.

Sway Frame 0

The bottom surface of the lower north flange was contacted at two separate locations. Between 92 and 102 inches from the face of the vertical, the lower surface was contacted and bent upward. Another smaller contact mark was at 230 inches from the vertical but no deformation was visible. Blue paint transfers were present at both locations. See Figure 20.

The U0W-L0W vertical was distorted at the lower end of the sway brace connection and again at deck height.

Span 8 Sway Frame Damage Summary

A graphical summary of damage to the sway braces is presented in figure 21.

Sway Frames Span 7

Similar impact damage was noted on the sway frames 6, 5, 4, 3 and 2 of span 7. Details are presented below. Measurements were again referenced from the roadside vertical face of the associated vertical members. The roadway was intact in span 7 and the fog line on the roadway was located approximately 35 inches from the inside faces of the vertical members.

Sway Frame 6

Due to the proximity of sway frame to the unprotected edge of the pier the damage was not closely examined and the locations of damage were estimated from a distance. The lower flange of the sway brace had damage at two locations. Markings were apparent on the lower north flange between 45 and 57 inches. No flange deformation was obvious and the damage appeared superficial. Both north and south flanges were damaged and distorted between an estimated 81 an 92 inches. Both flanges were bent upward and the north flange was creased. See Figure 22.

Sway Frame 5

The lower surfaces of sway brace 5 had three parallel gouges partially across the north flange and completely across the south flange. The gouges were between 45 and 53 inches from the vertical and were accompanied by blue paint transfers. An additional scuff mark was present between 63 and 66 inches of the north flange, also with blue paint transfer. See Figure 23.

An old corroded contact mark was located at 77 inches. The mark was accompanied by a small dent in the flange.

Sway Frame 4

Sway frame 4 and the associated U4W-L4W vertical member were heavily damaged. The sway brace was impact damaged beginning at about 30 inches from the vertical and extending to at least 65 inches. In this area the lower north flange was rolled down and to the south with blue paint transfers noted on the north edge and top surface of the flange. The lower north flange was horizontally torn between 38 and 55 inches with a missing section centered at 45 inches. See Figure 24.

The sway frame was distorted and bowed to the south beginning near the vertical and across about 25% of the width of the span. The distortion bowed the sway brace an estimate 12 inches to the south.

The U4W-L4W vertical member was distorted to the south and east centered at the sway brace attachment area. The deflection was estimated to be about 12 inches to the south and several inches to the east. See Figure 24 Upper and Figure 25.

Sway Frame 3

A scrape mark was found on the underside of the lower flange of the sway brace at 59 inches. The 1.5 inch wide north-south scrape extended across the full width of the north flange and onto the south flange. No distortion was noted in the flanges.

A corroded previous contact mark was noted on the lower flanges at about 80 inches from the brace. See Figure 26.

Sway Frame 2

A north-south oriented scrape mark was noted on the underside of the south flange at 81 inches from the vertical. The scrape was about 6 inches long and 1 inch wide with blue paint transfers evident. See Figure 27.

Sway Frame 1 and 0

No recent marks were noted on either sway braces 1 or 0.

Span 7 Sway Frame Damage Summary

The lateral locations and approximate extents of recent damage to the sway braces of both span 7 are illustrated in figure 28 in relationship to the deck and travel lanes. Damage to span 8 (figure 21) is also presented

Oversize Load

Inspection of the oversize load (casing shed) revealed impact damage to the upper right corner of the box structure. In addition, the normally rectangular casing shed was racked from front to back with the roof displaced rearward. See Figure 29. The exterior of the load was painted blue consistent with the blue paint transfers found on various components of span 7 and 8.

According to the manufacturer[6], the upper portion of the casing shed was made from “grade 50W mild steel” with 4 W18X46[7] wide flange beams roof runners spanning the length of

[6] Thunder and Lightning Welding LTD, Leduc, Alberta Canada
[7] I-beam structural steel shapes, nominally 18 inches tall with 6 inch wide 0.6 inch thick flanges and 0.36 inch webs.

the shed. Eleven gauge[8] sheet steel covered the roof and sides of the shed. The roof runners were tied together along their lengths by multiple 3 and 4 inch channels at the top and bottom of the runners. The roof runners are supported by 6 X 6 X ¼ inch HSS[9] corner posts and a 6 X 4 X ¼ inch HSS rim frame. All components are fully welded together.

Four heavy impact marks were apparent on the front, upper right corner of the load in the roof area above the rim frame. The lowest mark displayed a curvature that closely approximated the curvature of the north portal and sway braces. See Figure 30. The heaviest damage was at the right side outboard roof runner where the sheet metal covering was cut completely through.

The paint on the roof of the shed was marked and intermittently scuffed along the entire right side above the runner. See Figure 31. Additional scuffing was visible on the left side near the aft end of the shed.

Joe Epperson
Senior Metallurgist

[8] 11 gauge steel is nominally 0.1196 inch thick.
[9] HSS, Hollow Structural Shape

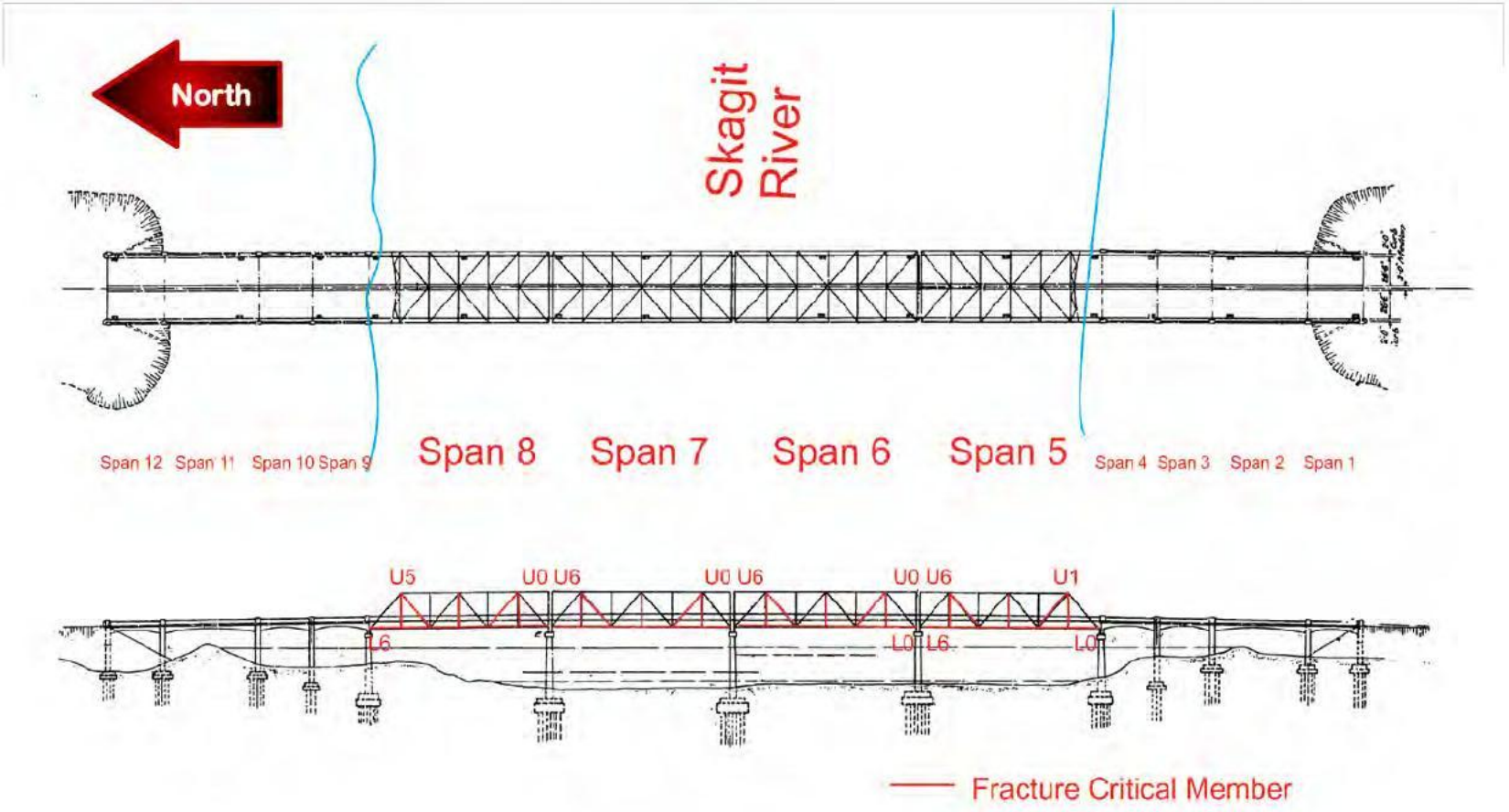

Figure 1. Schematic of the I-5 bridge over the Skagit River. Fracture critical members are shown in red.

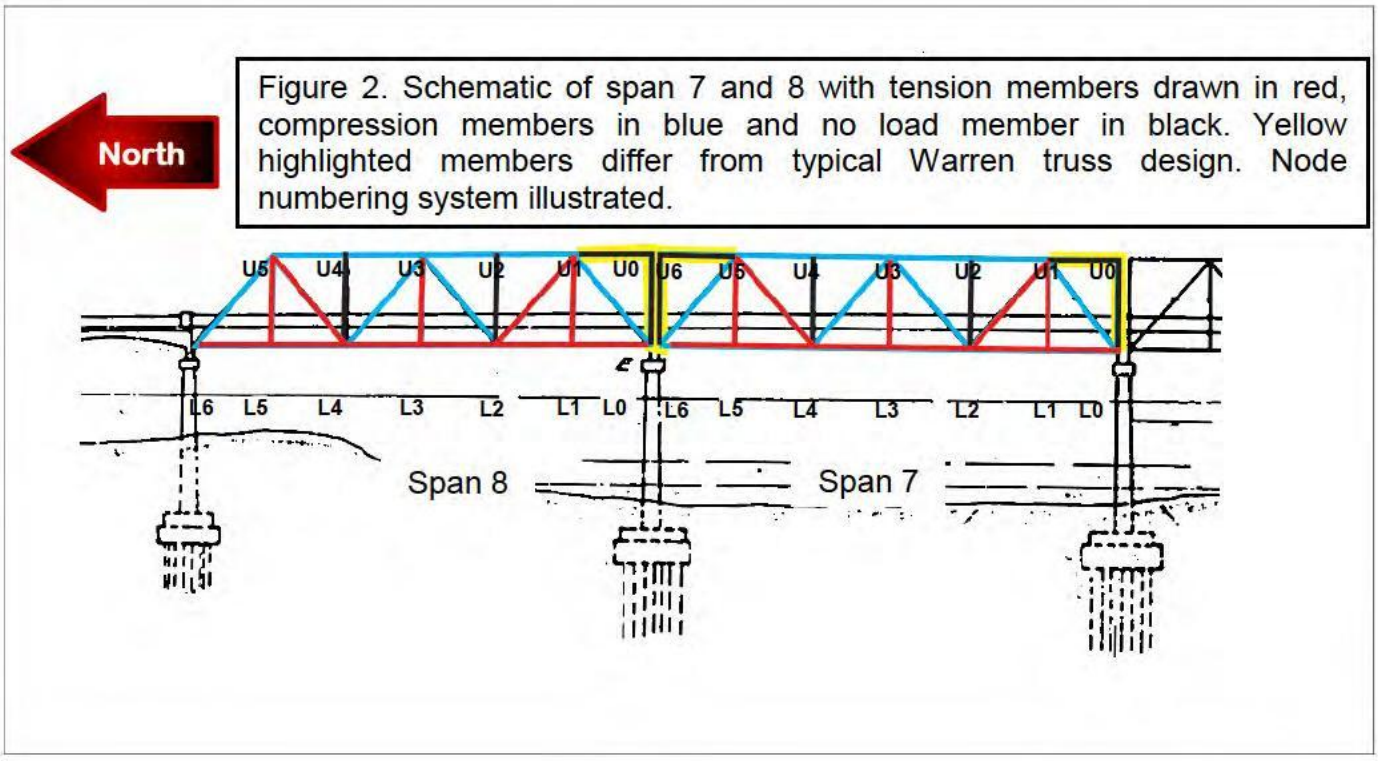

Figure 2. Schematic of span 7 and 8 with tension members drawn in red, compression members in blue and no load member in black. Yellow highlighted members differ from typical Warren truss design. Node numbering system illustrated.

Figure 3. View looking south at the north portal prior to the collapse.

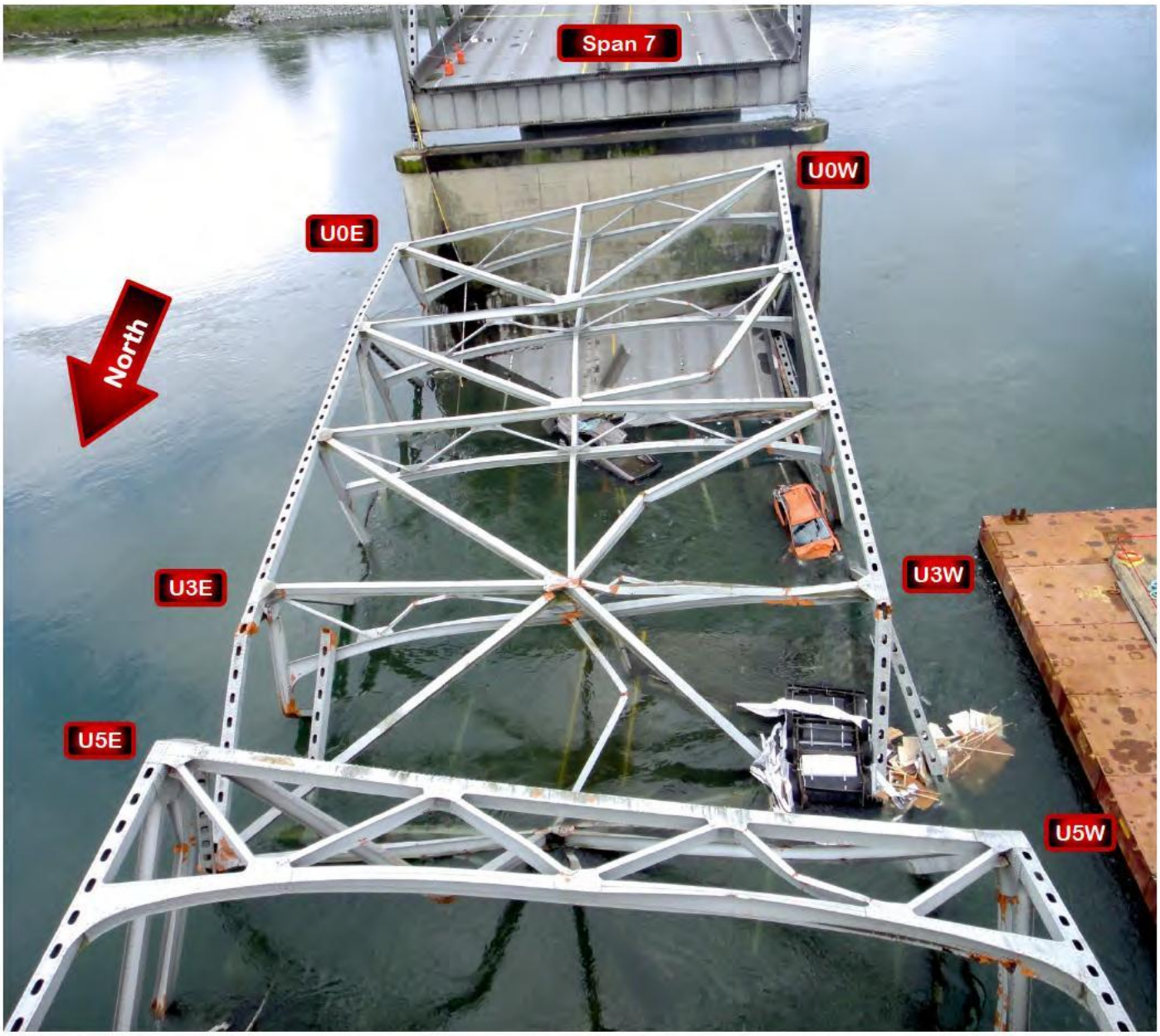

Figure 4. View looking down and south from the north pier at the collapsed span 8. "V" appearance of fallen structure between U3 and U5.

Figure 5. Two views of collapsed span 8 from the downstream (west) side. "V" appearance of fallen structure between U3 and U5.

Figure 6. A view of node U3W and the surrounding damage.

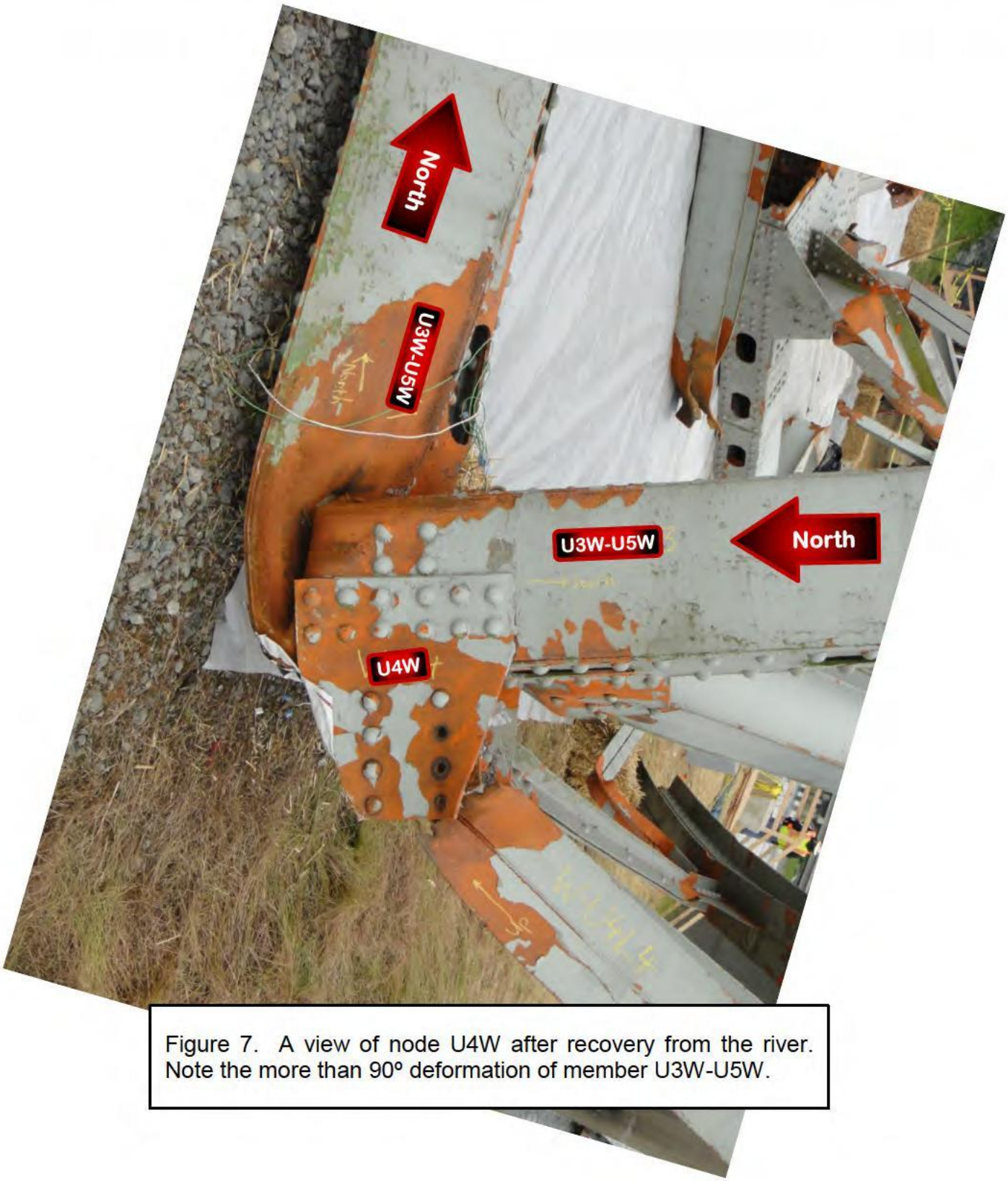

Figure 7. A view of node U4W after recovery from the river. Note the more than 90° deformation of member U3W-U5W.

Figure 8. Two more views of the deformation at U4W. Lower view shows trapped pieces of the camper trailer.

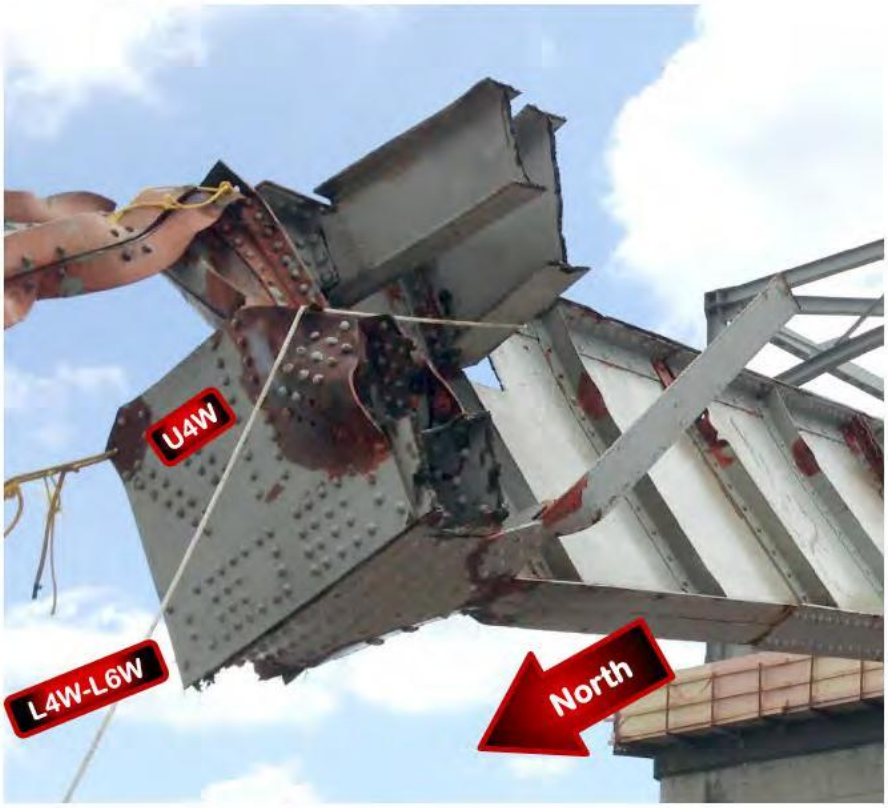

Figure 9. At left, node L4W being recovered attached to floor beam 4. Below, two views of bending overstress fractured member L4W-L6W.

Figure 10. Top, an overall view of node U5W with a view of overstress fractured member U3W-U5W below.

Figure 11. Node U4E with separated member U3E-L4E.

Figure 12. Node U4E as-collapsed at left and after recovery below.

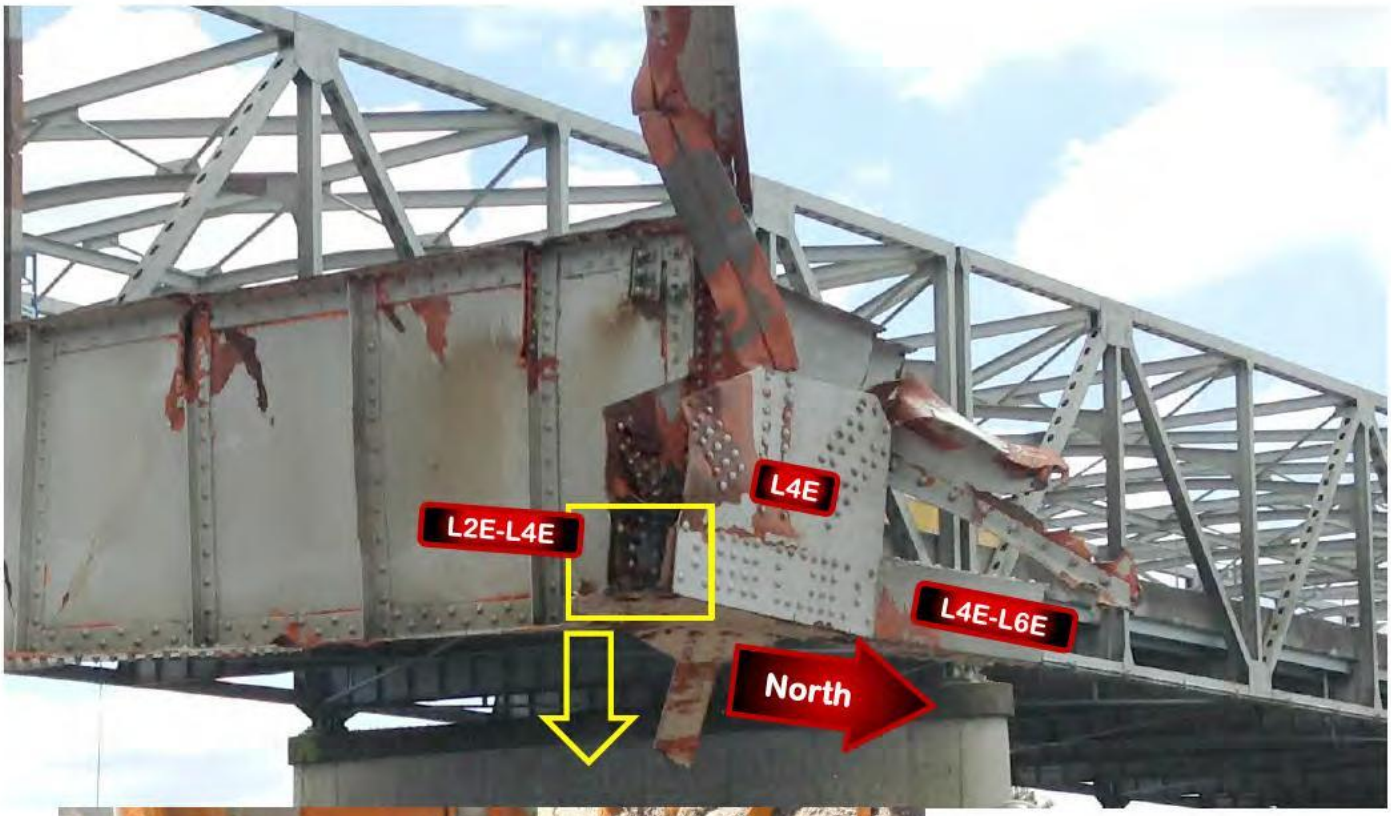

Figure 13. Node L4E attached to floor beam 4 above during recovery. The fracture face of member L2E-L4E at left.

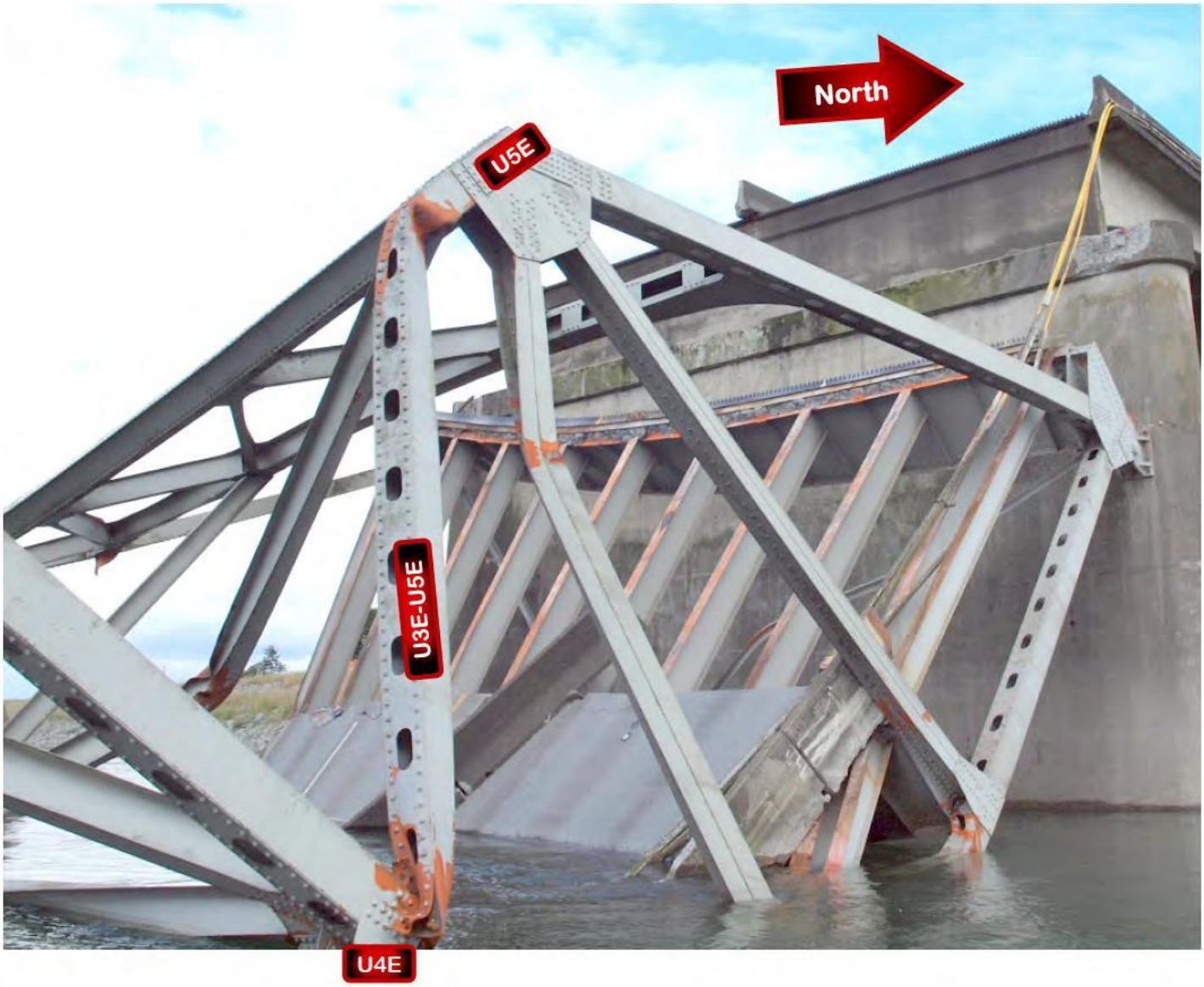

Figure 14. Nodes U5E and U4E on the collapsed structure.

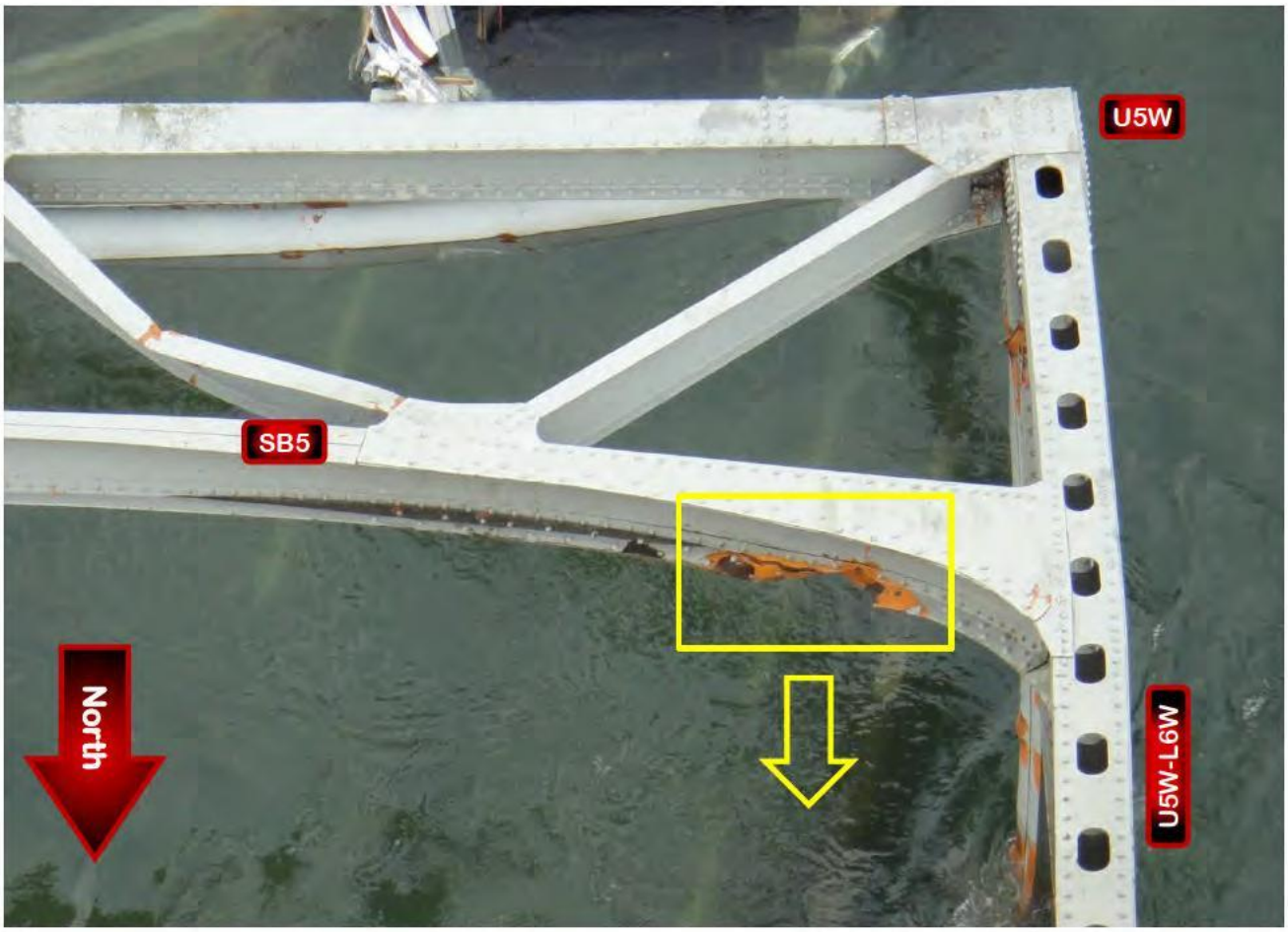

Figure 15. Impact damage to the north portal over the outside travel lane, yellow box in the upper view. A corner shape was evident in the damage as indicated by the yellow brackets in the lower view.

Figure 16. Impact damage to sway brace 4 above with extent of bowing depicted below.

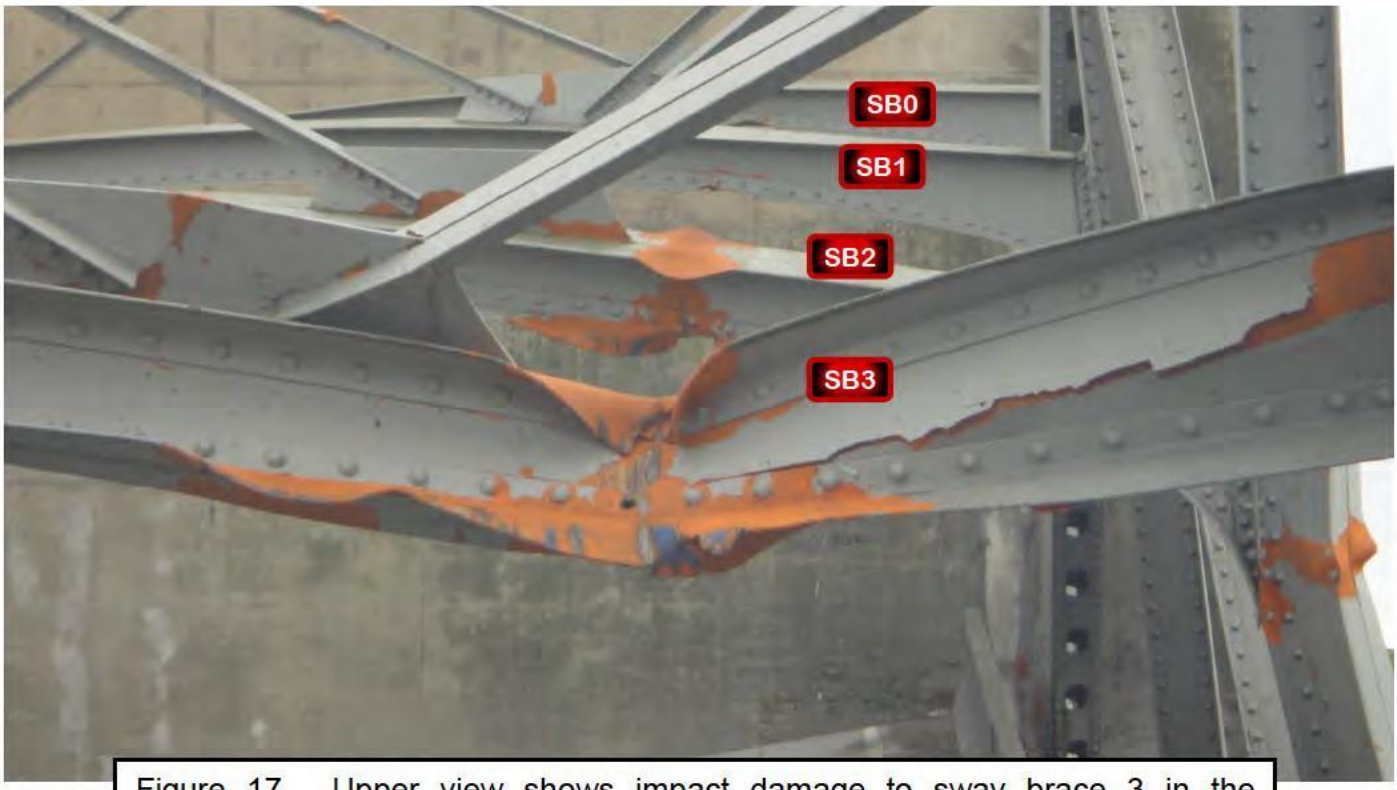

Figure 17. Upper view shows impact damage to sway brace 3 in the foreground along with impacts on SB2, 1 and 0 in the background. Separation of SB3 from vertical U3W-L3W is depicted below. Both views looking south.

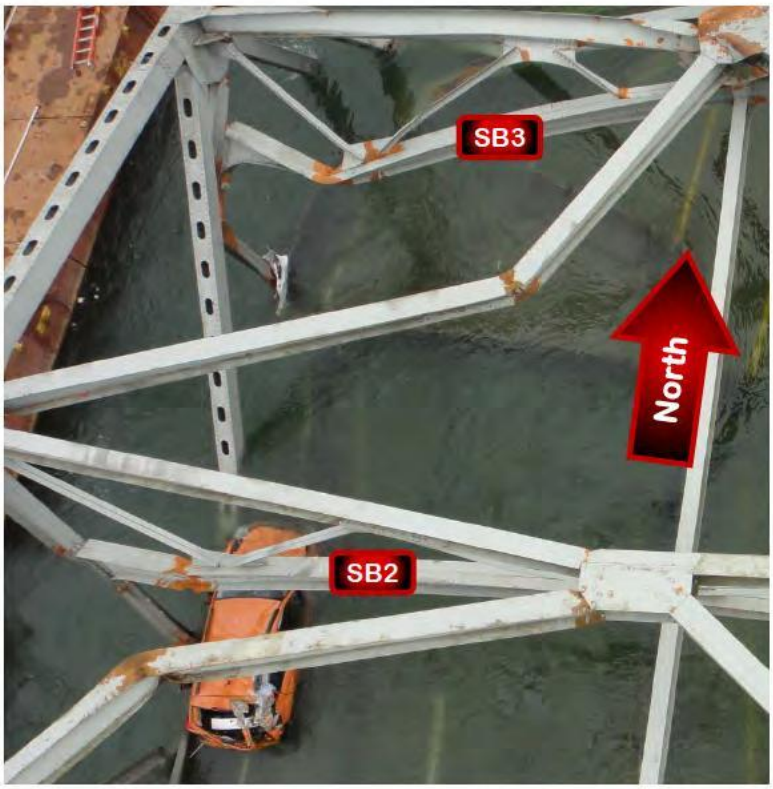

Figure 18. Overhead view of damage and bowing on SB3 and SB2, at left. Lower view shows impact damage to SB2.

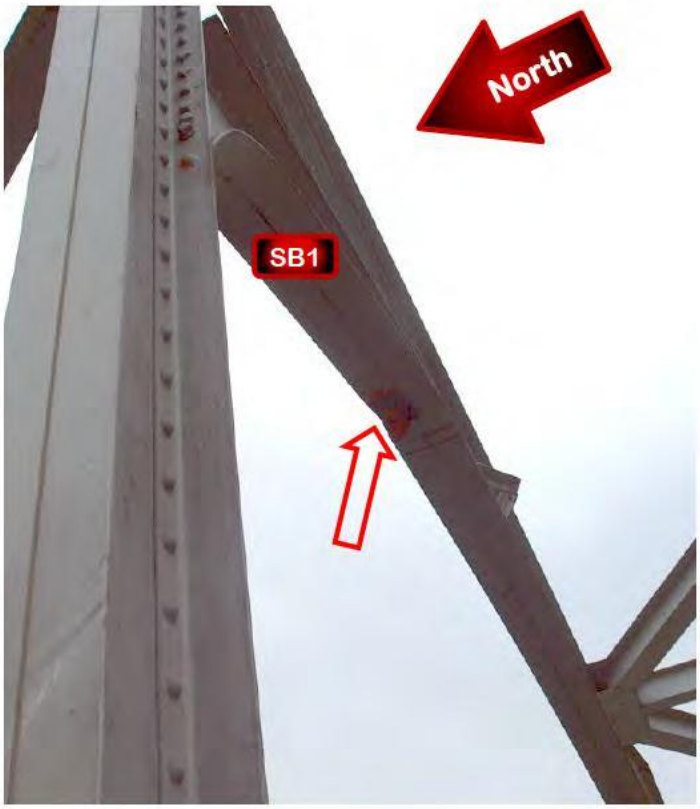

Figure 19. View of damage (red arrows) to SB1.

Figure 20. View of damage (red arrows) to SB0.

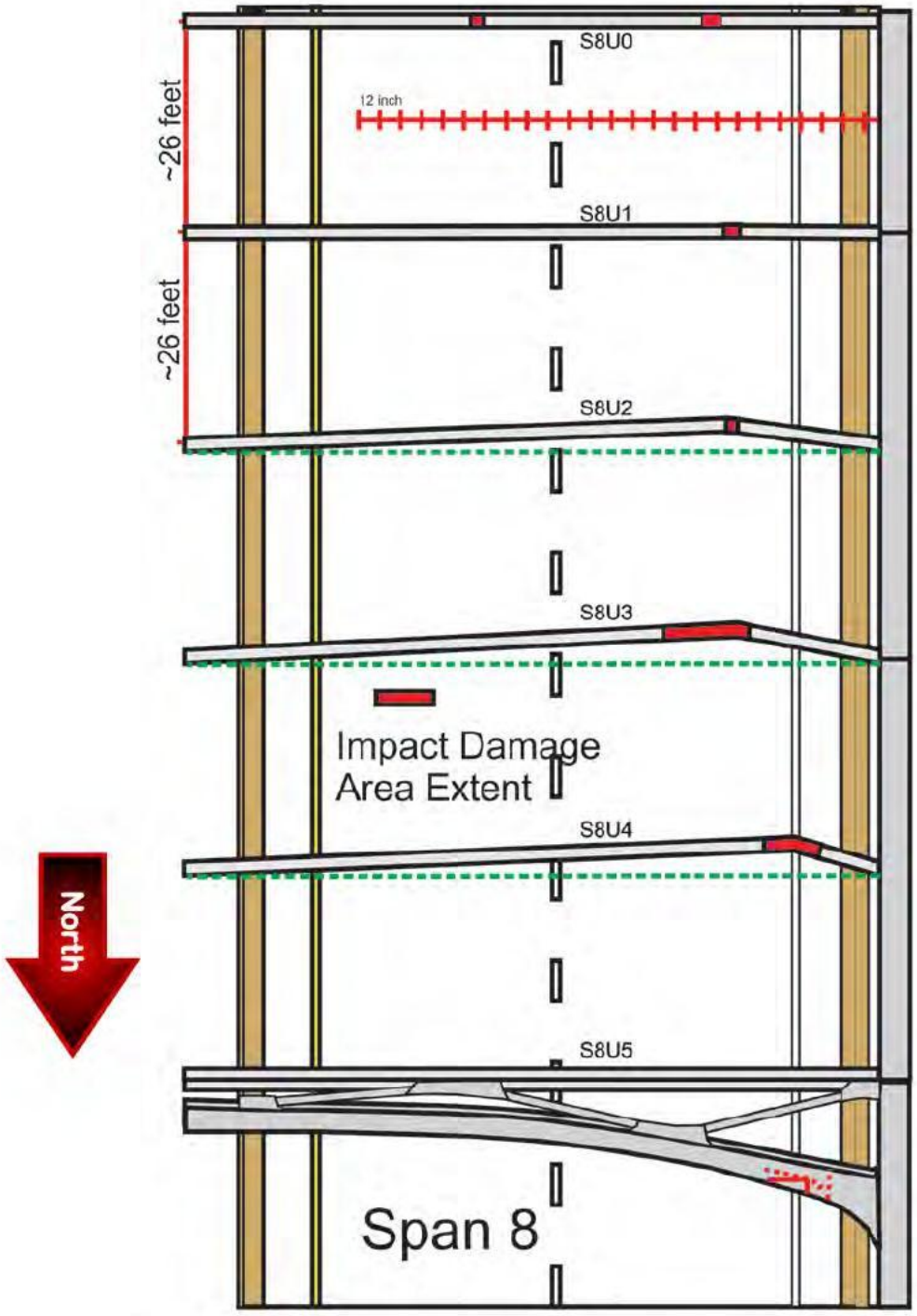

Figure 21. Top view illustration depicting damage to sway braces in span 8. Red areas denote approximate location and extent of damage. Bowing of sway braces also indicated. Measurement approximate.

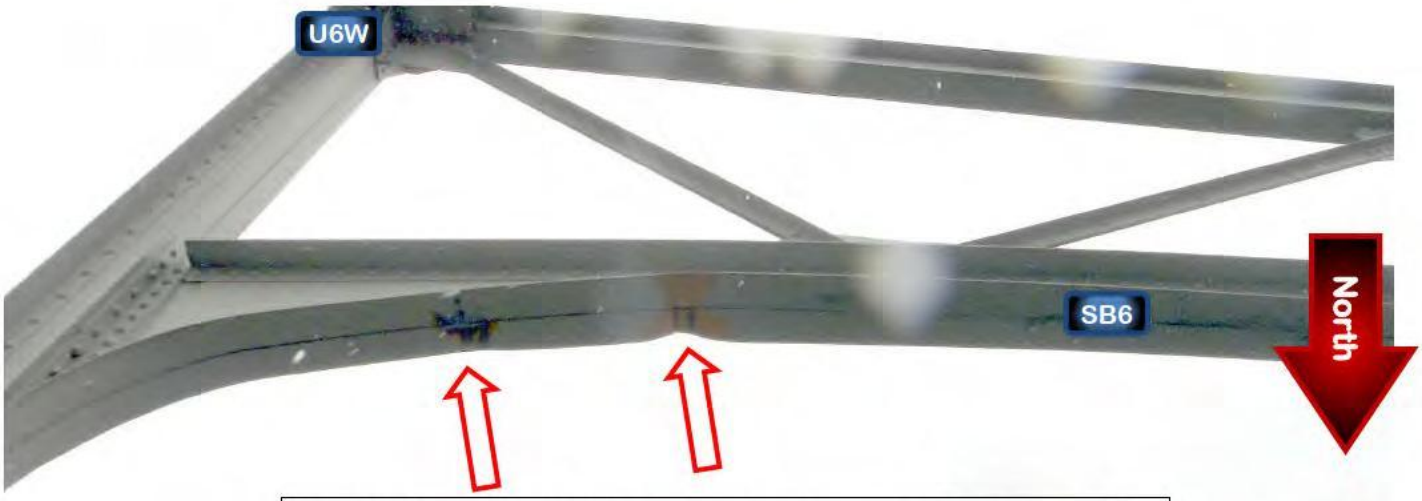

Figure 22. View of damage (red arrows) to SB6 on span 7.

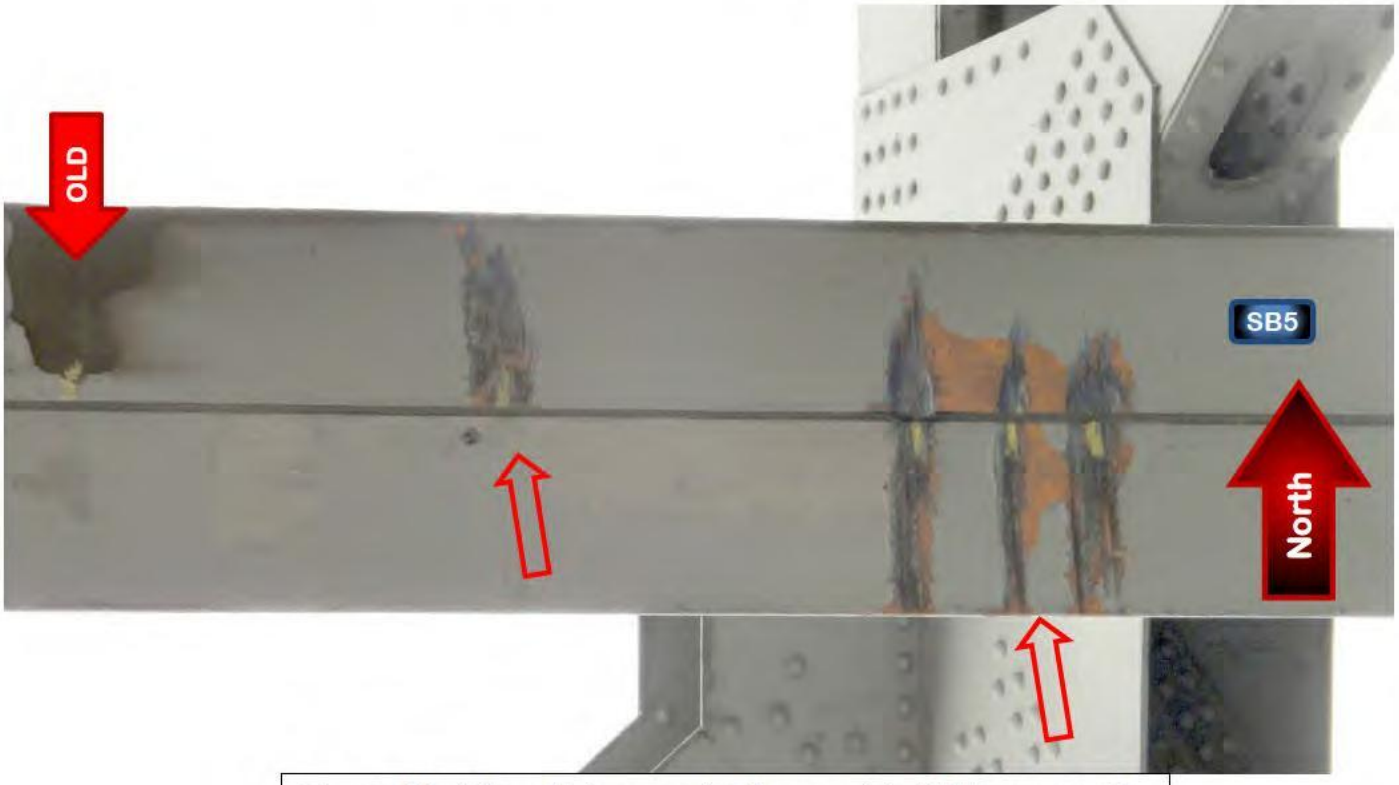

Figure 23. View of damage (red arrows) to SB5 on span 7.

Figure 24. Damage to SB4 (yellow box left) and vertical U4W-L4W. Note eastward bow of the vertical at left. A closer view of the sway brace damage is shown below.

Figure 25. Looking west at damage to vertical L4W-U4W and SB4. Bowing of both members to the south.

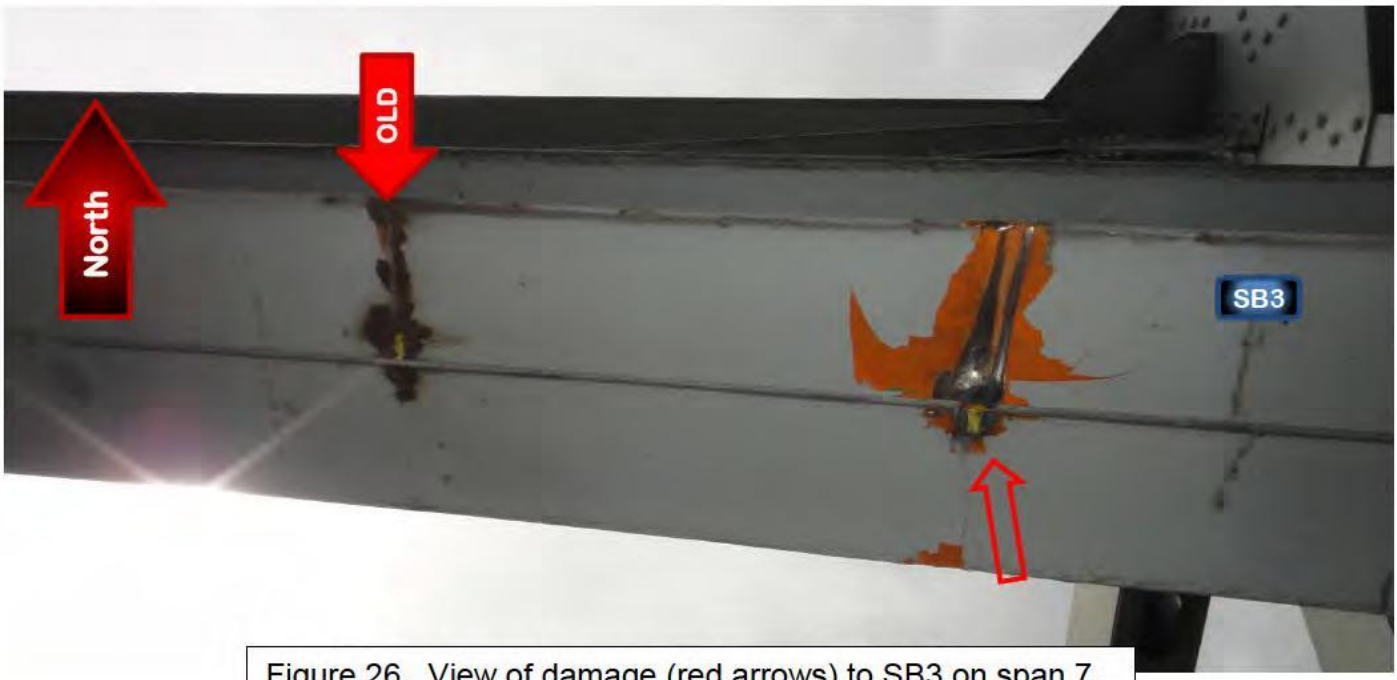

Figure 26. View of damage (red arrows) to SB3 on span 7.

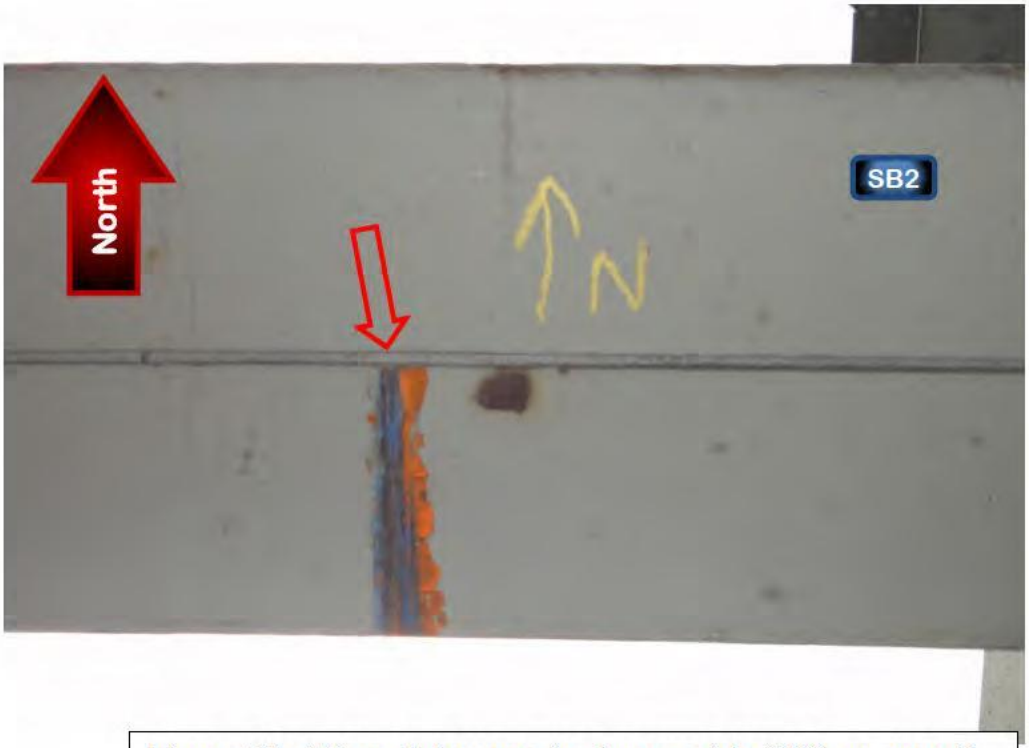

Figure 27. View of damage (red arrows) to SB2 on span 7.

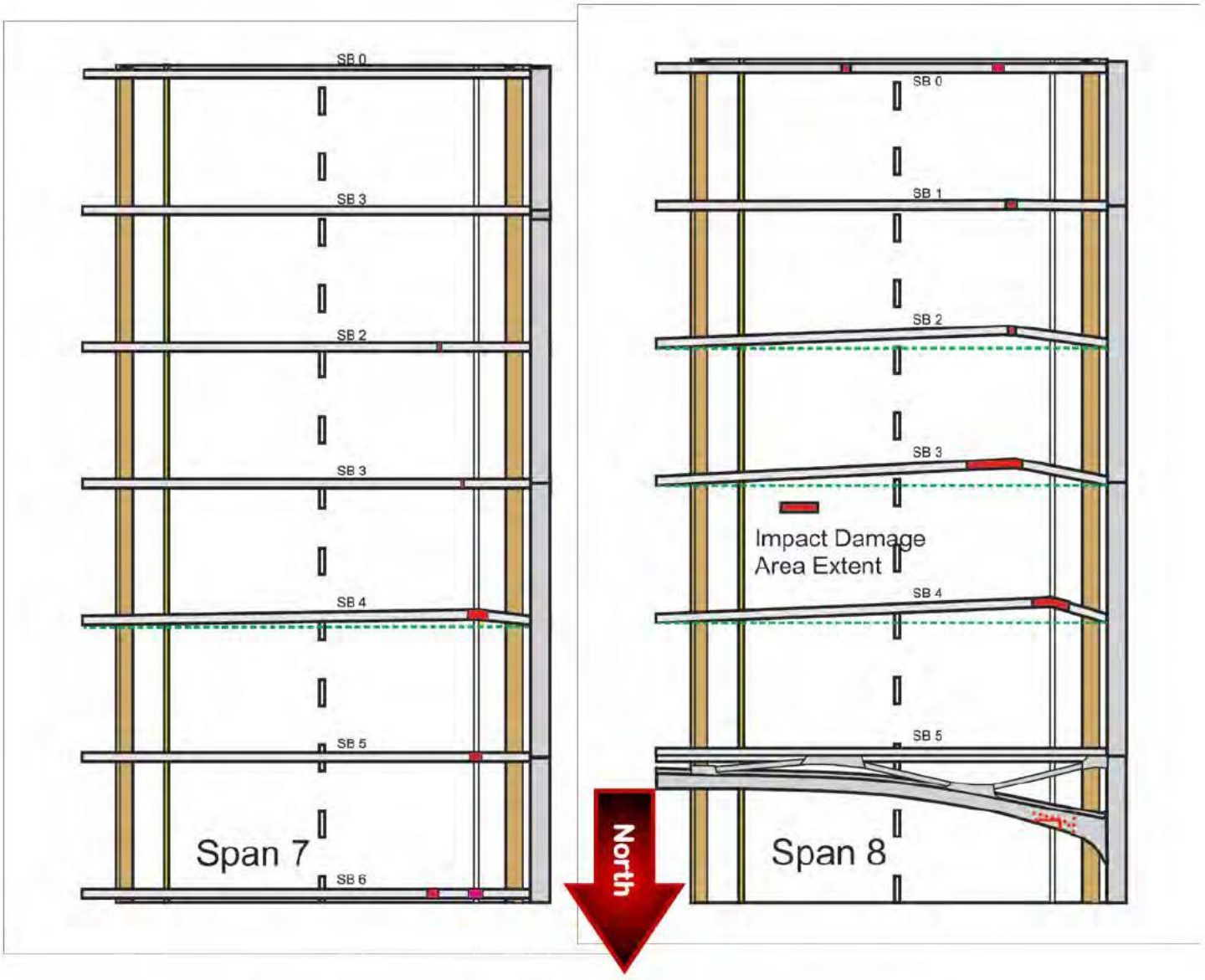

Figure 28. Top view summaries of damage to the span 7 sway braces at left with span 8 damage at right. Measurements are approximate.

Figure 29. A side view of the casing shed at top showing the racking. Dotted red lines shown only as a visual reference. Left view is looking rearward at the front of the casing shed with the impact damage (yellow box) in the upper right corner of the shed. Boxed area shown in figure 30.

Figure 30. Closer view of the damaged area (boxed area from figure 29) from the front (top view) and top (left view).

Figure 31. Scuff marks along the right side top of the shed. Viewed looking forward.